Dynamics of Soil Organic Matter under Slash-and-Burn Agriculture in a Semiarid Woodland of Zambia(Digest_要約)

AUTHOR(S):

Ando, Kaori

Dynamics of Soil Organic Matter under Slash-and-Burn Agriculture in a Semiarid Woodland of Zambia

Kaori Ando

2014

Contents

Chapter 1 Introduction

Soil organic matter (SOM) is important for sustaining cropland productivity for farmers in the semiarid tropics of Africa who use little fertilizer and rely on the nutrients released from SOM (Lal, 1997). The SOM content of soil, which decreases during clearing and cropping, has typically been restored during a fallow period under slash-and-burn agriculture in Africa (Nandwa, 2001). However, the conversion of woodland to cropland followed by a shortening of the fallow period has been increasing as a result of increased land use pressure, which may lead to a decrease in SOM (Nandwa, 2001). During typical slash-and-burn practices in Eastern Province, Zambia, trees are cut only within the field being opened, and the cut trees are piled only in part of the field because woodland biomass is typically quite low. Only the spots with tree piles can be burned; the remaining cleared spots will not be burned. Recently, because most emergent trees have disappeared with the shortened fallow periods, the trees piles composed of bush trees has been increasing. Thus, the spots unburned and burned with emergent and bush trees piles could be present simultaneously within a cleared field after burning. The extent of burning or the fire intensity, which can be determined by the maximum temperature and the duration of burning (Hatten and Zabowski, 2009), affects the amount of SOM degraded and nutrients released (Strømgaad, 1992). The decline in during cropping after burning has been attributed to various factor: high rates of mineralization of SOM (Tinker et al., 1996), the incorporation of plant materials, the breakdown of soil aggregates by plowing (Six et al., 2002), and the decrease in the input of organic matter returned to the soil (Huggins et al., 1998). However, the effect of the fire intensity on the decline in SOM during cropping has not been reported. It should be concerned that the decrease in SOM during cropping with different fire intensities could be restored during the recent shortened fallow. Restoration of SOM during the fallow has been attributed to an increase in litter returned to soil (Funakawa et al., 2006), and low decomposition rates for SOM (Huggins et al., 1998). Several studies have reported that a short fallow was not enough to recover the decreased SOM (Hauser et al., 2006), while it depends on the extent of the decrease in SOM during cropping (Mobbs and Cannell, 1995). The objectives were to evaluate the effects of fire intensity on SOM and nutrient release immediately after burning (Chapter 3), to evaluate the changes of C and N content in labile SOM under different cropping periods followed by a short fallow with reference to the changes in the input returned to the soil (Chapter 4), and to estimate C and N budgets during cropping and a short fallow based on input and output flow (Chapter 5).

Chapter 2 Description of study site

The study site is located in a village in Eastern Province, Zambia, in southern Africa (14°08'S, 31°43'E, Fig. 2.1). The climate has a unimodal distribution of annual rainfall with a rainy season from November to April, and a dry season during the remaining months (Fig. 2.2). Annual rainfall in the rainy season averaged 855 mm and the mean annual air temperature was 24°C. The soil was classified as Typic Plinthustalfs. The soils at the depth of 0–15 cm in the long fallow had a pH of 6.8 with water to soil ratio of 5, soil texture of sandy loam containing 67% sand, 20% silt and 13% clay, total C of 1.3% and total N of 0.08%.

A flat 100 × 230 m woodland site was selected with uniform soil C and N stocks and vegetation. Land clearing was conducted using conventional techniques as previously described in the Introduction. Within each field being cleared and opened, three levels of fire intensity existed, unburned spots after clearing (85.6% of the total field), burned spots with piles of bush trees (7.5%), and burned spots with piles of emergent trees (6.9%).

To establish cropping and short fallow rotation plots, a site that had been opened by slash-and-burn was divided into three 12 × 31 m plots, used as replicates. After 1-year cropping, cropping continued in some of the plots, while others were returned to fallow every year. The treatments consisted of cropping for 1, 2, 3, 4, and 5 years and fallow for 1, 2, 3, and 4 years after each 1-, 2-, and 3-year cropping. Each plot has the spots unburned and burned with emergent tree and bush tree. A 20 × 30 m long-term fallow plot was also marked inside the experimental site. To establish the plots with long-term cropping and a short fallow rotation, three fields with 10-year cropping and two fields with 40-year cropping were selected in the village; fertilizer had never been applied to the study plots. The plots were divided into cropping and fallow treatments (15 × 15 m) in October 2010. A long fallow plot was also established close to each long cropping plot.

Fig. 2.1
Location of study site

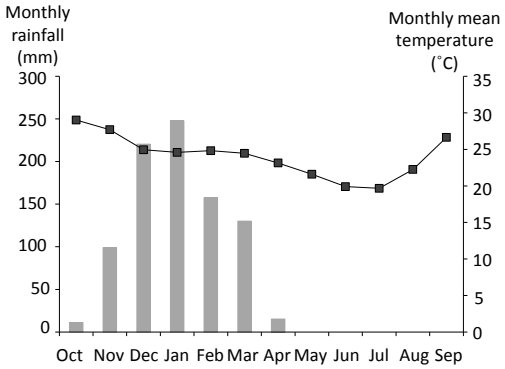

Fig. 2.2
Rainfall and monthly mean temperature of study site

Chapter 3 Short-term effects of fire intensity on soil organic matter and nutrient release after slash-and-burn

In Eastern Province, Zambia, the spots unburned and burned with emergent and bush trees piles could be present simultaneously within a cleared field after burning. Because emergent and bush tree piles burned differently, variations were observed in fire intensity and this affected soil organic matter (SOM) degradation and nutrient release. The fire intensity was significantly higher in burned spots with emergent tree piles in terms of maximum temperature and duration of burning. Soil C stock decreased by 25.1% and 14.7% in burned spots with emergent and brush tree piles, respectively, while soil N stock decreased by 15.0% only in burned spots with emergent tree piles and did not change significantly elsewhere. Additionally, the mortality of soil microbes caused by soil heating resulted in an increase in C mineralization after burning. The levels of available nutrients, such as NH_4–N, available P, as well as exchangeable K and Ca, increased following the decomposition of SOM and microbial mortality that occurred with an increase in fire intensity. Net N mineralization did not occur, especially in burned spots with emergent tree piles because the N content of labile organic matter decreased. As a result, maize grain yield increased with fire intensity, which was also attributed to the limited weed biomass in the burned spots caused by soil heating. Although the burned emergent and bush tree piles occupied only 6.9 and 7.5% of total cleared field, respectively, the grain yield in burned spots with emergent and bush trees accounted for 21% and 15% of the total yield, respectively. Thus, the recent decrease in emergent trees has caused high spatial variability of fire intensity inside the cleared field, which in turn caused high spatial variability of the amount of SOM, available nutrients, and grain yield. Grain yield may decrease in the current system as more areas are being burned with bush trees because emergent trees are decreasing, although the severe decrease in SOM may be alleviated.

Table 3.1
The effect of fire intensity on soil organic matter, available nutrients, and grain yield

Treatment	Soil stock					Grain yield
	Total C ($Mg\ ha^{-1}$)	Total N ($Mg\ ha^{-1}$)	Avairable P ($kg\ ha^{-1}$)	Exchangeable Ca ($kg\ ha^{-1}$)	Exchangeable K ($kg\ ha^{-1}$)	($Mg\ ha^{-1}$)
Unburned[¶]	18.3 a	1.3 a	107 a	1,381 a	305 a	0.9 a
Bur S[¶]	15.6 b	1.2 a	338 b	1,354 a	372 ab	2.4 b
Bur L[¶]	13.7 b	1.1 b	920 c	2,151 b	408 b	3.5 c

[¶]The spots unburned (Unburned), and burned with bush (Bur S) and emergent (Bur L) trees.

Chapter 4 Effects of cropping and a short-natural fallow rotation on soil organic matter

The effect of cropping and a short fallow on soil organic matter (SOM) was different among three different fire intensities within the cleared field. The C and N content of SOM (SC and SN, <2000 μm), coarse organic matter (COM-C and COM-N, >2000 μm), particulate organic matter (POM-C and POM-N, 2000–53 μm), and the composition and the amount of plant materials returned to soil were measured.

During short-term cropping in the unburned spots, SOM and grain yield did not change. However, the labile fraction of COM-C and POM-C decreased gradually because the proportion of woody weeds decreased during cropping, which decomposed slowly. The low decrease in SN and POM-N might be attributed to the low maize production and leachate. After returned to fallow, only POM-C could recover in fallow after 3- and 10-year cropping because of the high input of litter and retarded decomposition that occurred when plant litter was left on the surface. The decrease in SN caused by long-term cropping did not recover in the short fallow because the few woody plants available could not redistribute N from deeper soil via litter fall.

On the other hand, the high maize yield lasted for only 1 and 2 years at the burned spots with bush and emergent trees, respectively. A decrease in C content of all the soil fractions caused by burning tended to recover during the short cropping period at the burned spots with emergent trees, while only labile soil fractions of C decreased and recovered gradually at the burned spots with bush trees. This reflected the large amount of input as ash and maize stems were returned to the soil in 1- and 2-year cropping. Although the decrease in SN caused by burning did not change during short cropping at burned spots, POM-N recovered during cropping at the burned spots with emergent trees. This occurred partly because of the redistribution of N from the MOM fraction via input of plant materials. After the land was returned to fallow, the C and N content of all the fractions did not change irrespective of fire intensity.

The spatial variability of SOM and woody biomass induced by burning was still high after cropping and a short fallow. Recovery of woody biomass decreased with an increase in the previous cropping period and fire intensity. At the unburned spots, 2-year fallow after 3-year cropping is relatively sustainable management in terms of maintenance of POM, SOM, and grain in the case of the cropping after clearing long fallow. In addition, SOM including the labile soil fraction could not recover during a short fallow at the burned spots. Although the SOM decreased by burning, the rate of decrease in SOM was slow during the short cropping in the entire cleared field.

Chapter 5 Soil carbon and nitrogen budgets during cropping and short-natural fallow rotation

The changes of soil C and N stocks during cropping and short fallow rotation at unburned and burned spots were evaluated by the C and N budgets. Soil C and N stocks decreased by burning could not be fully restored during a short fallow period, although the soil C stock was gradually restored during 1- and 2-year cropping. After burning, the annual decomposition of organic matter in 1- and 2-year cropping was lower than the input returned to soil because the input was composed of plant materials that decomposed slowly. Nevertheless, soil N stock decreased by 56 kg ha^{-1} after 1-year cropping because the annual loss was high as the result of a large loss of N via leaching and maize production. N loss, especially by burning, was not recovered during a short fallow because of low N input into the soil.

In addition, soil C and N stocks at unburned spots apparently did not decrease during cropping and fallow. The fact that soil C stock did not decrease during cropping for 4 years was attributed to the large total C input when compared with the annual decomposition of organic matter; that is, a large amount of slowly decomposable input occurred during the 1-year cropping. After the land was returned to fallow, at the unburned spots the annual decomposition of organic matter was balanced with the input of organic matter. Input of C was larger than the annual decomposition of organic matter only in a 2-year fallow after 3 years of cropping. Because harvesting, woody growth, and leaching resulted in only a low level of N loss during cropping and fallow, the even small input of N via rainfall and litter could affect the N budget; then, the changes of soil N stock would be negligible. However, the N budget became negative after fields were left fallow for more than 4 years because of the high N loss via the increased woody growth increment. Then, in case of the cropping after clearing a long fallow, 3-year cropping and 2-year fallow was a relatively useful rotation in unburned spots. With the return of plant residue, the decrease in soil C and N stock during cropping was small. The C and N stock could not be fully recovered, especially in burned spots, but did not fall drastically with cropping and a short fallow rotation in the region at both burned and unburned spots.

Chapter 6 Summary and conclusion

Figure 6.1 shows the results of cropping and a short fallow rotation. Cropping for more than 10 years exhausted soil organic matter (SOM) and woody biomass; then, SOM and woody biomass were not restored during a short fallow. At burned spots with emergent and bush tree piles, SOM decreased only by burning and could be restored during short cropping, although N contents of SOM and woody biomass were not restored even during the fallow. Without burning, a 2-year fallow after 3-year cropping is a relatively useful management technique in terms of maintaining particulate organic matter, SOM, and grain yield, although woody biomass decreased compared with 1-year cropping. The C and N stock could not be fully recovered, especially in burned spots. However, no drastic loss of SOM was caused by the use of cropping and a short fallow rotation in the region at both burned and unburned spots. In this region, the decrease in soil C and N stock during cropping was small with the return of plant residue because the long dry season constrains the loss of SOM through leaching and decomposition while N fixation by free-living N_2 fixing bacteria increases soil N content.

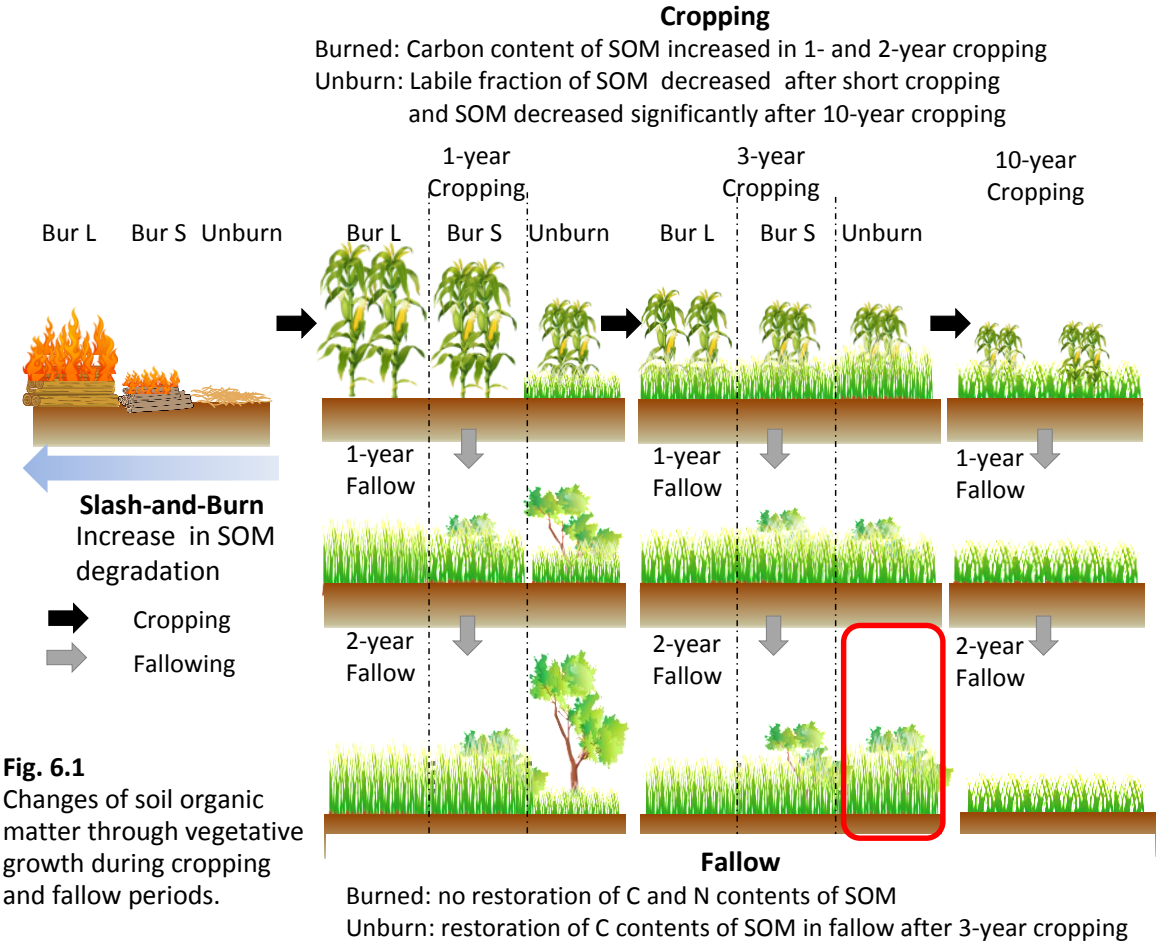

Fig. 6.1
Changes of soil organic matter through vegetative growth during cropping and fallow periods.